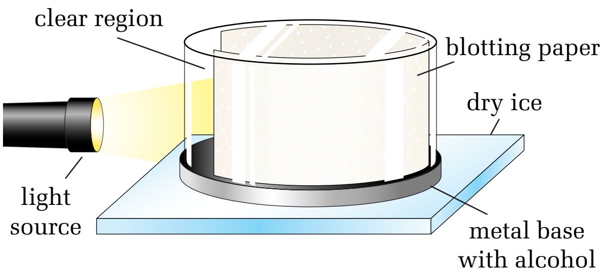
INVESTIGATION 13-B

The Wilson Cloud Chamber

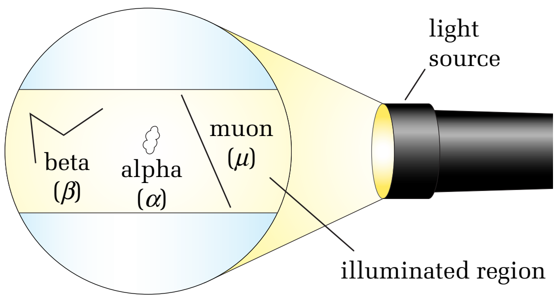
TARGET SKILLS
- Performing and recording
- Analyzing and interpreting

The cloud chamber that you will use consists of a short, transparent cylinder with a glass top and a metal base. The sides are lined with blotting paper, except for a section through which you will shine an intense light beam, as shown in the diagram. The light will make the liquid drops visible against the dark background.



The next diagram shows the general appearance of some tracks that you might see. Alpha radiation appears as a short (1 cm to 2 cm long), thick puff of white "cloud." Beta particles (high-speed electrons) appear as long, thin strands that bend gradually or zigzag from collisions with atoms.

Because the muon is much more massive than the beta particle, it appears as a thin, extremely straight strand that goes across the chamber. Many muons angle downward and are difficult to observe.



Since Earth is constantly bombarded by cosmic rays (which are really high-energy particles), you can nearly always observe tracks in a cloud chamber.

Equipment

- cloud chamber
- radioactive source (optional)
- light source
- alcohol
- dry ice

CAUTION Do not touch dry ice unless you are wearing thick gloves.

Procedure

1. Place the cloud chamber on the block of dry ice and pour in the alcohol to a depth of about 1 cm. Put on the glass cover and let the chamber stand for a few minutes, until the alcohol has a chance to reach equilibrium.
2. Working in groups of three or four, take turns watching the cloud chamber carefully for a total of at least 15 min. Make a sketch of every track that you see.
3. Obtain similar data from all of the groups that are performing the observations.
4. (Optional) If your cloud chamber has a small access hole in the side and if you have a small radioactive source on the end of a pin, insert it into the hole.
5. Make a sketch of the tracks that you observe emanating from the source.

Analyze and Conclude

1. Try to identify the tracks that you observed.
2. List the types of radiation observed in this investigation, from the most common to the least common.
3. What type of radioactive source did you use? Were the tracks consistent with the nature of the radiation emitted by the source? Explain.

and if they are charged, through the electromagnetic force, but are immune to the strong nuclear force. Once called the "beta decay interaction," the weak nuclear force is involved in beta decay.

As you would probably expect, electrons and electron neutrinos are leptons. Muons and their neutrinos are also leptons. A more recently discovered particle, the tau (τ) particle and its neutrino, also fit into the lepton family. As previously stated, for every particle, there is an antiparticle. The antiparticles always have the same mass as the particle, and if the particle has a charge, the antiparticle has the opposite charge. When the particles are neutrally charged, the antiparticle is also neutral but opposite in some other property. In such cases, the antiparticles are denoted with a bar over the symbol. Leptons and their antiparticles appear to be true elementary particles. There is no indication that they consist of any more fundamental particles.

Particles of the **hadron** family interact through the strong and weak nuclear forces. Hadrons can also interact through the gravitational force, and if they are charged, through the electromagnetic force. The hadron family is the largest family and is subdivided into the groups, mesons and baryons. The common proton and neutron and their antiparticles are baryons, while pions are mesons. Pions were at one time called "pi mesons." As larger and more powerful particle accelerators were built, more and more hadrons were discovered.

Table 13.4 summarizes the properties of most of the subatomic particles that have been discovered. However, the list of hadrons is incomplete and will certainly continue to grow as physicists continue their search. Since most of the particles are very short-lived and are eventually transformed back into energy, Table 13.4 reports the energy equivalent of the rest masses of the particles in units of MeV, rather than reporting in units of mass. If you calculated the energy equivalent of 1 u, you would find that it is about 931.5 MeV.

Quarks

As the number of hadrons that had been discovered grew, physicists became suspicious that hadrons might not really be elementary particles. Some physicists were studying the scattering of electrons off protons and neutrons and saw evidence that there were three "centres" of some type within the nucleons. At the same time, theoretical physicists Murray Gell-Mann (1929–) and George Zweig (1937–), working independently, proposed the existence of truly elementary particles that made up hadrons. Gell-Mann somewhat jokingly called these particles **quarks**, from a line in *Finnegan's Wake* by James Joyce — "Three quarks for Muster Mark." The name stuck. Today, physicists accept that quarks are the elementary particles of which all hadrons consist.

Table 13.4 Some Particles and Their Properties

Family	Particle	Particle Symbol	Antiparticle symbol	Rest energy (MeV)	Lifetime (s)
Photon	photon	γ	self*	0	stable
Lepton	electron	e^-	e^+	0.511	stable
	muon	μ^-	μ^+	105.7	2.2×10^{-6}
	tau	τ^-	τ^+	1784	10^{-13}
	electron neutrino	ν_e	$\overline{\nu}_e$	≈0	stable
	muon neutrino	ν_μ	$\overline{\nu}_\mu$	≈0	stable
	tau neutrino	ν_τ	$\overline{\nu}_\tau$	≈0	stable
Hadron					
Mesons	pion	π^+	π^-	139.6	2.6×10^{-8}
		π^0	self*	135.0	0.8×10^{-16}
	kaon	K^+	K^-	493.7	1.2×10^{-8}
		K^0_S	$\overline{K}^0_S$	497.7	0.9×10^{-10}
		K^0_L	$\overline{K}^0_L$	497.7	5.2×10^{-8}
	eta	η^0	self*	548.8	$<10^{-18}$
Baryons	proton	p	$\overline{p}$	938.8	stable
	neutron	n	$\overline{n}$	939.6	900
	lambda	Λ^0	$\overline{\Lambda}^0$	1116	2.6×10^{-10}
	sigma	Σ^+	$\overline{\Sigma}^-$	1189	0.8×10^{-10}
		Σ^0	$\overline{\Sigma}^0$	1192	6×10^{-20}
		Σ^-	$\overline{\Sigma}^+$	1197	1.5×10^{-10}
	omega	Ω^-	Ω^+	1672	0.8×10^{-10}

*The particle is its own antiparticle.

At the time that quarks were proposed, three quarks and their antiquarks could account for all known hadrons. Mesons consisted of two quarks, and baryons consisted of three quarks, given the names "up" (u), "down" (d), and "strange" (s). Uniquely, quarks have fractional charges of $+\frac{2}{3}e$, $-\frac{1}{3}e$, $-\frac{1}{3}e$, respectively, while the antiquarks have charges of the same size but opposite charge. Figure 13.19 gives examples of the quarks that make up the common neutron, proton, and positive and negative pions. Notice that the baryons consist of three quarks and the mesons consist of two.

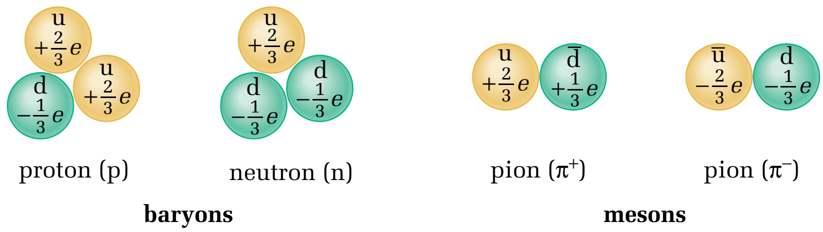


Figure 13.19 The combination of quarks in hadrons always results in a neutral charge or in a unit charge.

The quark model worked very well in explaining the properties of hadrons until about 1974, when more hadrons were discovered. Eventually, physicists discovered that six quarks were necessary in order to account for all of the newly discovered hadrons. The three new quarks were given the names "charmed" (c), "top" (t), and "bottom" (b), although some physicists, particularly in Europe, prefer to call the last two quarks, "truth" and "beauty." The quarks and some of their properties are summarized in Table 13.5.

Table 13.5 The Quarks

Quark name	Rest energy (GeV)	Quark		Antiquark	
		Symbol	Charge	Symbol	Charge
up	0.004	u	$+\frac{2}{3}e$	$\bar{u}$	$-\frac{2}{3}e$
down	0.008	d	$-\frac{1}{3}e$	$\bar{d}$	$+\frac{1}{3}e$
strange	0.15	s	$-\frac{1}{3}e$	$\bar{s}$	$+\frac{1}{3}e$
charm	1.5	c	$+\frac{2}{3}e$	$\bar{c}$	$-\frac{2}{3}e$
top (or truth)	176	t	$+\frac{2}{3}e$	$\bar{t}$	$-\frac{2}{3}e$
bottom (or beauty)	4.7	b	$-\frac{1}{3}e$	$\bar{b}$	$+\frac{1}{3}e$

As physicists collected more and more details about hadrons and their quarks, they discovered that quarks have more properties than just charge. A property that physicists call "colour" explains many of their observations, as well as placing the quark in agreement with the Pauli exclusion principle.

Exchange Particles

Physicists' current view of the structure of matter is summarized in Figure 13.20, but this summary does not present the complete picture. You have read many times about the four fundamental forces of nature, the properties of these forces, and how elementary particles are even categorized according to the forces that they

experience. The question remains: How do these forces work? While studying elementary particles, physicists also discovered some basic information about the fundamental forces of nature. The **standard model** refers to the currently accepted mechanisms of the strong, weak, and electromagnetic forces. Physicists hope to bring the gravitational force into the model, but so far, it has been elusive.

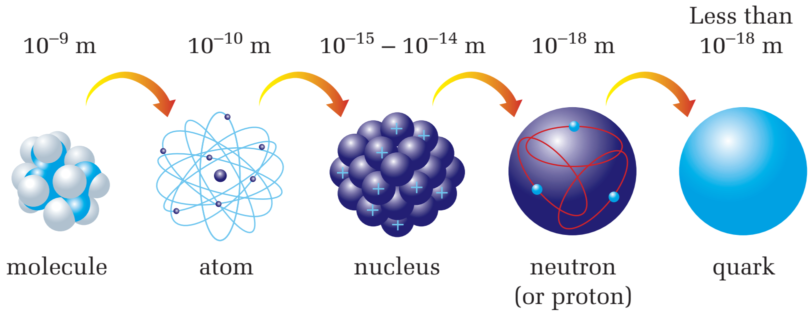


Figure 13.20 Scientists' view of the smallest indivisible piece of matter has changed greatly over the past century — going from Dalton's model of the atom to the current view of the quark.

Physicists have found particles that are exchanged by the elementary particles that account for the interactions between them. Some of the properties of these exchange particles are listed in Table 13.6.

When charged particles interact through the electromagnetic force, they exchange a photon. Because photons have no mass and travel at the speed of light, the range of the force is unlimited. In the opposite extreme, the weak nuclear force is mediated by bosons that have a large mass and such a short lifetime that the range of the interaction is extremely short.

Table 13.6 Force Carriers

Force	Name of Particle	Symbol	Mass (GeV)	Charge	Range (m)
electromagnetic	photon	γ	0	0	unlimited
weak nuclear	weak boson	W^+ W^- Z^o	80.2 80.2 91.2	$+e$ $-e$ 0	10^{-17}
strong nuclear	gluon	g	0	0	10^{-15}
gravitational	graviton*	G	0	0	unlimited

*The graviton has been proposed as a carrier of gravitational force. However, its existence has yet to be confirmed.

The exchange of gluons holds quarks together in hadrons. The theory is that when quarks exchange gluons, they change colour. Physicists have proposed the existence of a graviton as an exchange particle for the gravitational force and have determined some of the properties that such a particle would have to have. However, they have never observed any indication that gravitons exist. As you can see, the story is far from complete and there are many more challenges ahead for elementary particle physicists.